2018 EUVL Workshop

Workshop Summary

(Meeting Notes. Please notify author of any errors.)

Vivek Bakshi, EUV Litho, Inc.

CXRO
THE CENTER FOR X-RAY OPTICS

EUV
LITHO, INC.

Workshop Summary – June 13, 2018

- **Session 1: Keynote – 1**
- **EUV Lithography at the Threshold of High Volume Manufacturing** (P1)
  Harry J. Levinson, *GLOBALFOUNDRIES*
- Most recent results comparing LE3 and single exposure EUV show similar results in electrical performance and yield
- **Considerations for HVM are: Equipment reliability, Yield, Particles on masks, Process control**
- Equipment reliability is most critical and biggest problem still is light source
- Cycle time advantage of EUVL over 193i may be lost from mask qualification delays
- Are pellicles ready for production?
- Process control hard due to things like mask 3D effects
- **Second generation EUV lithography will require OPC on steroids and more photons**

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- **Session 1: Keynote – 1**
- **Current status, Challenges and Outlook of EUV lithography for High Volume Manufacturing (HVM)** (P4) Britt Turkot, *Intel Corporation*
- **NXE3400 availability reaching 80%, need higher. NXE3400 platform is more reliable than 3300. Source remains the top contributor to lack of availability. Caution: data comes from small number of scanners which get lots of attention.**
- 250 W power requirements are being met.
- Significant improvement in collector lifetime. 0.25% loss per GP at 250 W (125W) established
- Stable CD performance trend over 1 yr
- NXE3400 cleaner overall but unpredictability of adder events drives need for pellicles. Pellicle defectivity is at Zero (>10 Micron particles). 245 # today – 300 is the goal
- **Yellow items are pellicles and AIMS. Only red item is APMI.**

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- **Session 2: EUV Masks**
- **Electron Multi-Beam Technology enabling EUV Mask Writing** (P35) (Invited Presentation)
  Hans Loeschner, *IMS Nanofabrication*

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- **Session 2: EUV Masks**
- **Advances in High-volume Manufacturing of EUV Mask Blanks: Current Status and Roadmap** (P37) (Invited Presentation) Katrina Rook, *Veeco Instruments Inc*
- 20 years of involvement in EUV market
- Veeco IBD-LDD is the tool-of-record for EUV mask blanks multilayer (ML) deposition
  - Tool meet requirements for 7nm technology node
  - Actively working to improve for future node
- **Ion beam etch is a viable option to pattern near future absorber materials**
- Ion beam deposition can be extended for highly uniform absorber layer

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- **EUV mask substrate readiness for sub10 nm HP nodes** (P34) (Invited Presentation)
  - Abbas Rastegar, *Applied Materials*
- EUV mask blank performance is determined by many interdependent parameters of substrate that need to be optimized simultaneously
  - Surface flatness (PV, local slope and bow)
  - Surface roughness
  - Defectivity
  - Multiple polishing tools and cleaning tools and process need to be optimized.
- **As multilayer deposition processes are becoming efficient, substrate yield will be the main driver for the price of the EUV blanks**
- The higher power EUV source and pellicles will generate more heat on substrate that require LTEM materials be optimized for higher temperature (Higher T_{ZC})
- **Applied Materials has demonstrated considerable improvement in substrate development within a year**
  - **Defectivity: 3 order of magnitude reduction→ 6@ 34 nm**
  - **PV: 6x reductions→ PV=52 nm (16 nm Adv. polishing)**
  - **Bow: 25x reduction→ bow = 6 nm**

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- **Advanced Deposition Techniques for Next Generation EUV Mask Blanks** (P61)
  - Vibhu Jindal, *Applied Materials*
- Applied's Advanced Deposition technologies can address future EUV mask requirements
- **Using various materials engineering techniques, Applied has**
  1. **improved CrN backside properties,**
  2. **reduced the Mo/Si intermixing for the mirror layer,**
  3. **optimized the TaN layer,**
  4. **identified viable thin absorber materials,**
  5. **and continues to explore material systems at an accelerated pace.**

- Next steps include validation of new material systems as an option for next generation EUV mask blanks
  - validation of etch-ability, cleaning durability, and imaging performance

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- **EUVL Mask Engineering in the Third Dimension: The Impact of Absorber Side-wall Angles on Imaging Behavior** (P38) (Invited Presentation)
  - Tim Fühner, *Synopsys*
- **Observations find that an undercut absorber side wall angle (SWA) improves ILS while maintaining reasonable depth of focus and exposure latitude**
- Propose the following working hypothesis:
  - Undercut absorber side walls reflect a fraction of light across the pattern void
  - Undercut absorber side walls absorb the intensity node created at the light side absorber
  - These two phenomenon create a more uniform intensity across the pattern void
  - The uniform intensity leads to a steeper intensity slope -> improved contrast
- Scattering and leakage should be greater in the undercut situation than the 90^{o} situation, but it appears the reflective phenomena are more significant than scattering and leakage

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- **Evaluating Thermal and Mechanical Properties of Composite Films for EUV Pellicle Applications** (P33)
  - Seong Ju Wi, *Hanyang University*
- The fabrication platform of pellicle composite based on SiN_x core layer including thermal or mechanical reinforcing layer is ready
- Mechanical behavior of CNT pellicle composite was investigated by bulge-test, the mechanical properties such as plane-strain modulus and residual stress were derived
- The optimal thickness of thermal emission layer was determined
- The HVM applicability of pellicle composite including thermal emission layer was confirmed

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- **Session 3: EUV Mask Metrology**
- **Coherent EUV Imaging and Metrology with High-harmonic Generation Sources** (P31) (Invited Presentation)
  - Stefan Witte, *ARCNL and VU University Amsterdam*
- High harmonic generation is a compact and versatile source of coherent EUV radiation for metrology
- The broad bandwidth of HHG sources allows spectroscopic characterization (identification) of materials
- Spectrally resolved lensless EUV imaging is possible through coherent diffractive (lensless) imaging techniques

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- **Session 3: EUV Mask Metrology**
- **Full Field Imaging at 13.5nm in Reflection and Transmission Modes using Coherent High Harmonic Beams for EUVL and Materials Metrology** (P32) (Invited Presentation)
  - Christina Porter, University of Colorado, Boulder
- Buried layer imaging - highly sensitive to interface profiles; quantitative, composition determination possible
- 13nm Reflection imaging near grazing allows wide field of view & directional high resolution on general samples, so long as spatially dependent oversampling is considered

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- **Application of EUV Diffraction Optics for Actinic Mask Inspection and Metrology** (P36)
  - Kenneth C. Johnson, *KJ Innovation*
- 1. EUV microlenses can be fully achromatized over a 2% EUV spectrum.
  - ✓ **Schupmann-doublet microlenses can provide fully achromatic, aberration-free point imaging with 23% efficiency.**
- 2. Zero-aberration imaging can be achieved over a large image field with an ***economical*** projection system.
  - ✓ **The microlenses can zero out all optical aberrations in the projection system.**
- 3. A parallel spot-scanning system could provide useful capabilities and benefits for actinic EUV inspection and metrology.
  - ✓ **zero-aberration, diffraction-limited illumination points for high detection sensitivity**
  - ✓ **far-field detection for good phase sensitivity**
  - ✓ **full-mask scan with high throughput**

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- **Mask 3D effects First Experimental Measurements with NA 0.55 Anamorphic Imaging** (P62) (Invited Presentation)
  - Vincent Wiaux, *IMEC*
- Reported FIRST NA0.55 EXPERIMENTAL BF-shift measurements using ANAMORPHIC SHARP imaging system and ORFEO, a dedicated mask.

- Validated the measurement methodology using ORFEO & SHARP by comparison to rigorous simulations.

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- **A SHARP Look at Future Nodes of EUV Lithography** (P64)
  - Markus Benk, *CXRO, LBL*
- SHARP High-NA Actinic Reticle Review Project is up and working
- Emulation of imaging in EUV scanner
- Emulation of anamorphic imaging
- Increased imaging performance with thinner absorber both for 0.33 and 0.55 anamorphic
- Source Optimization demonstration

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- **Session 4: EUV Optics and Contamination**
- **Optics for EUV Lithography** (P22) (Invited Presentation)
  - Sascha Migura, *Carl Zeiss SMT GmbH, Germany*
- Optics for EUV Lithography have evolved over three decades to a level where excellent imaging is demonstrated.
- Right now, the Starlith® 3400 Optics extends EUV Lithography to 13nm single-shot resolution with high productivity for serial production.
- High-NA EUV Lithography enables further shrink for the semiconductor industry to continue Moore's Law.

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- **Session 4: EUV Optics and Contamination**
- **Corrosion – Resistant Mg-based multilayer coatings for sources > 25 nm** (P23) (Invited Presentation)
  - Regina Soufli, *LLNL*
- Atmospheric corrosion has prevented the use of Mg/SiCmultilayers in applications requiring good lifetime stability, such as EUV laser sources and solar physics
- We have developed Al-based barrier layers that dramatically reduce corrosion in Mg/SiCmultilayers, while preserving high reflectance
- Corrosion barrier layers can be customized specifically for each multilayer design and environmental conditions
- Mg/SiCwith Al-based corrosion barriers has been implemented in upcoming EUV solar physics missions
- Investigation of the physics of spontaneous intermixing and amorphization of sputtered Al and Mg layers is ongoing

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- **A Sustainable Approach to Next Generation EUV Manufacturing** (P21) (Invited Presentation)
  - Supriya Jaiswal, *Astrileux*

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- **Ion Fluxes Impacting Surfaces Exposed to EUV Induced Plasma** (P25)
  - T.H.M. van de Ven, *University of Technology Eindhoven*
- Characterized the ion fluxes towards surfaces exposed to EUV-induced plasma

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- **Poster Session (6- 7:30 PM, Bay view Café)**

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- **Continued Scaling in Semiconductor Manufacturing with Extreme-UV Lithography** (P3) (Keynote Presentation) Anthony Yen, *ASML*
- Installed base of EUV systems is expected to double in 2018 to 20, 3 shipped so far
- Received 4 orders from 3 customer for high NA system
- 3400B uptime improving to >90% for 2018/2019 HVM, extending productivity to >150 W/hr @ 20 mJ/cm²
- Power overhead decreased from 30% to 10% via increasing target laser isolation
- 10 x improvement in mask defectivity. Plans to achieve 1 adder per 10 K pass in 2018
- **Throughput of 140 WPH achieved at 246 W (20 mJ dose, full fields)**
- **3rd gen droplet generator lifetime is now 780 hours**
- **Progression of EUVL**
  - **1st gen, k1~0.45, PC-SMO, straightforward**
  - **2nd gen,k1<=0.4, More sophisticated**
  - **3rd gen, k1<=0.3, DTCO, double patterning**
  - **4th gen, NA=0.55 – 24 nm dense CH stitched**
  - **High NA- smaller mask 3D effect from higher mag and smaller CRAO**
- **410 W demonstrated (8.2 mJ pulse at 50 kHz)**

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- **Compact, Bright, Plasma-based EUV Lasers for Metrology** (P2)(Keynote Presentation)
  - Jorge. J. Rocca, *Colorado State University, Fort Collins, CO*
- Results from development and applications of EUV lasers (Capillary Discharge soft X-ray lasers), created from plasma in a capillary discharge
- 46.9 laser (Ne like Ar) – 3 mW, 0.1-0.8 mJ at 4 Hz
- 13.2 nm lasers from Cd^{+20} – μJ energy, 5 ps, 15 μ size, 400 Hz
- Extension of technique now to 5.85 nm lasers (Ionized Dy)
- This is now a turn-on key technology from CSU which can support metrology development for EUVL and advanced semiconductor manufacturing

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- **Fundamentals of PSCAR and Overcoming the Stochastic Problems of EUV Lithography** (P5)
  (Keynote Presentation)
  - Seiichi Tagawa, *Osaka University*

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- **Session 7: Resist and Patterning - I**
- **Pushing the Resolution Limits of Photolithography** (P42) (Invited Presentation)
  - Yasin Ekinci, *Paul Scherrer Institute*
- **Good overview of what we need to understand and what experiments are needed to understand how EUV resists work**
- We need to understand how macroscopic parameters (dose, absorption, Dill's parameters) related to microscopic parameters (Quantum yield, Secondary Electron Blurr)
- For a state-of-the-art CAR: QY is 3-8
- PAG-backbone interaction could be exploited to increase QY
- SEB: For non-CAR=~1-2 nm and for CAR=4-5 nm

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- **Session 7: Resist and Patterning - I**
- **EUV Resist: The Great Challenge of Small Things** (P48) (Invited Presentation)
  - S. Castellanos, *ARCNL*
- *Need* Roadmap of photoresist performance that includes defectivity
- Fundamental understanding of EUV induced processes, with main emphasis in **low energy electrons induced chemistry and stochastics**
- **Disruptive designs are needed within the next 2 coming years to fight stochastics and the SLR trade-off.** Some ideas:
  - Anisotropy
  - Separating absorption and electron-induced chemistry
  - Narrowing electron energy distribution (valence band electrons always there!)

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- **EUV Materials Solution** (P52) (Invited Presentation)
  - Yoshi Hishiro, *JSR*
- EUV resist is radiation chemistry, as compared to ArF chemistry, as we have intermediate step of secondary photon generation
- Development of new PAG/Resin enables breakthrough performance
- Resist sensitivity is improved by applying “Sensitizer Under layer”. The possibility of 32 nm Pitch @ under 10mJ was observed.
- Metal resists provide higher sensitivity and etch selectivity
- JSR partnered with imec enabling manufacturing and quality control of EUV lithography materials for the semiconductor industry.

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- **MTR Resist for Reduced LER in EUV Lithography** (P51)
  - C. Popescu, *University of Birmingham*
- Material stochastics has an important effect on the LER of the structures printed.
- Optimizing the multi- trigger ratio (MTR) significantly reduces the LER.
- Quenching effect on LER saturates for high MTR ratio.

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- **Session 8: EUV Sources**
- **High Power LPP-EUV Source with Long Collector Mirror Lifetime for Semiconductor High Volume Manufacturing** (P11) (Invited Presentation)
  - Hakaru Mizoguchi, *Gigaphoton*
- Good progress on all fronts, average power, availability ad collector life time
- Pilot#1 is up running to demonstrate HVM capability;
  - High conversion efficiency 5% is realized with Pre-pulse technology.
  - High speed (>90m/s) & small (20micron) droplet is realized.
  - Output power 250W in-burst power @50% duty (125W ave.) several min.
  - Output power 113W in-burst power @75% duty (85W ave.) 143hrs.
  - Pilot#1 system achieved potential of 89% Availability (2weeks average).
- Recent achievement for most critical challenges mirror life
  - -0.2%/Gpls with 125W ave. was demonstrated at short term dummy mirror test

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- **Session 8: EUV Sources**
- **Simulating EUV Emission from Laser-Produced Plasma** (P12) (Invited Presentation)
  - *Steven Langer,* Lawrence Livermore National Laboratory
- Experimental data has limits on spatial, temporal, and spectral resolution and can't answer some questions. It takes time and money to field a new EUVL source.
- The combination of experiment and simulation can improve EUVL sources faster than experiment alone.
- Simulations can be used to:
  - Perform parameter studies
  - Examine in detail conditions inside the target
  - Identify key physical processes
  - Provide initial experimental settings for a new EUVL source

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- **Characterizations of a Nd:YAG Laser-driven Plasma** (P13) (Invited Presentation)
  - Dmitry Kurilovich, *Advanced Research Center for Nanolithography (ARCNL)*
- Comparison of ns and ps pulse on tin droplets to define region of operation where less debris is produced
- Plasma induced pre-deformation of subsequent droplets
- Investigation of effect of initial shape of droplet on deformation

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- **Ar Plasma Discharge Sources for EUV/SXR Metrology and Imaging** (P24) (Invited Presentation)
  - Ladislav Pina, *Czech Technical University in Prague*
- **Ar^{8+} LASER 46.9 nm at CTU. Can be used as light source for metrology at 47 nm**
- EUV microscope with capillary discharge plasma source (Nitrogen, l = 2.88 nm), ellipsoidal grazing incidence condenser and Fresnel Zone objective

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- **Session 9: EUV Resist and Patterning - II**
- **Numeric Model for the Imaging Mechanism of Metal Oxide EUV Resists** (P46) (Invited Presentation)
  - W.D. Hinsberg, *Columbia Hill Technical Consulting*
- Simple model of MOx resist to establish quantitative link between photochemistry and imaging
- Contrast originates from non-linear oxo-network formation
- Lithographic predictions consistent with experimental observations

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- **Session 9: EUV Resist and Patterning - II**
- **LER tradeoffs for BEOL Patterning** (P40) (Invited Presentation)
  - Puneet Gupta, *UCLA*
- LER requirements can be harsh for EUV (<3nm for single patterning and <2nm for multiple patterning)
- Some relaxation possible by smarter optimization of design rules -Use larger spacing than width

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- **MET 5 Update** (Tentative title) (P45)
  - Chris Anderson, *LBL*
- Current status: First light, interferometry and validated interferometry with printing
- Next step is to align optics using interferometry before opening facility to users

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- **Fundamental Understanding of Chemical Processes in EUV Lithography** (P47)
  - *Oleg Kostko, LBL*
- Collaborative Team and Instrumentation is the National Lab Strength
- Targeted EUV dose for 7nm node --40 mJ/cm^2 = 27 photons/nm^2
- Study of EUV resist process – step 1- Photoionization and step 2 – electronic relaxation can be studies via photoelectron spectroscopy. While Step 3 of atomic relaxation and step 4 of inelastic scattering via mass spectrometry

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- **Using Resonant Soft X-ray Scattering to Image Patterns on Undeveloped Resists** (P53)
  - Guillaume Freychet, *LBL*
- GISAXS to study pattern development
- 3D reconstruction of the latent image with a sub-nm resolution
- Trapezoidal shape after the exposition. Comparison before and after development
- Quantification of the roughness